DETONATION OF PROTON GAS

By M. P. MURGAI

Defence Science Laboratory, New Delhi

(Received for publication, March 7, 1952)

ABSTRACT. The hydrodynamic theory of detonation has been applied to proton gas. Due to the very high value of the energy released in the proton-proton reaction, the calculated values of detonation parameters are much greater than those for chemical explosives. Due account of radiation pressure and energy has been taken.

The Chapman-Jouguet theory of detonation, when applied to chemical explosives, enables the various parameters of detonation to be determined from purely initial and final states of the explosive, along with a suitable equation of state for the products, without the knowledge of the intermediate kinetics. This fact suggests the extension of the theory to the nuclear explosive phenomenon. The present work is an attempt at calculating such parameters for proton gas enclosed in a cylindrical tube of uniform cross section. The postulated reaction, when the non-reactive shock traverses the gas, is the formation of deutron so that we have

$$ {}_1H^1 + {}_1H^1 \longrightarrow {}_1H^2 + \epsilon $$

Due to the high value of ϵ, as compared to that for ordinary high explosives, the temperatures are extremely high ; so that due account of the pressure and the energy of radiation has to be taken in applying the conservation laws. In fact, due to the very rapid variation of radiation pressure with temperature, as compared to the kinetic pressure, both are important simultaneously only in a very narrow range and the former is important beyond, and the latter is so, before that range of temperature. The change in the kinetic pressure in this case is much more due to high temperature, than due to compression by the pressure behind the shock. Therefore, it is predicted fairly accurately by the perfect gas equation $pv = RT$.

The radiation pressure $p_r = \frac{a}{3} T^4$, a being the energy density constant.

By the application of the laws of conservation of mass, momentum, and energy, we have in this case,

$$ D^2 \rho_0^2 = (p + p_r)\rho' \qquad \dots (1) $$

$$ W^2 = \left(\frac{p + p_r}{\rho'} \right) \qquad \dots (2) $$

$$1/\rho' = 1/\rho_0 - 1/\rho$$

$$(E+E_r) - \alpha\epsilon = \tfrac{1}{2}(p+p_r)(v_0 - v) \qquad \ldots \quad (3)$$

in which D and W are the detonation velocity and the particle velocity respectively, p and p_r are the kinetic pressure and the radiation pressure ; E, E_r are the thermal energy and the energy due to radiation ; ϵ, the heat of the reaction ; α is a parameter which takes account of the cross section of the reaction ; v_0, v are the specific volumes in the initial and the final states of the explosives.

From the relations

$$E_r = 3p_r v \qquad \ldots \quad (4)$$

$$E = \overline{C}_v T \qquad \ldots \quad (5)$$

$$T = \left(\frac{3}{a}\right)^{1/4} p_r^{1/4} \qquad \ldots \quad (6)$$

$$p = \frac{R}{v}\left(\frac{3}{a}\right)^{1/4} p_r^{1/4} \qquad \ldots \quad (7)$$

we have the Rankine-Huginiot equation

$$\alpha_5 p_r^{1/4} + 3.5 p_r v - \alpha_4 p_r - \alpha_2 p_r^{1/4}/v - \alpha\epsilon = 0 \qquad \ldots \quad (8)$$

where

$$\alpha_5 = \alpha_1 + \alpha_3 \qquad \ldots \quad (8a)$$

$$\alpha_1 = \overline{C}_v\left(\frac{3}{a}\right)^{1/4} \qquad \ldots \quad (8b)$$

$$\alpha_2 = \frac{R}{2}\left(\frac{3}{a}\right)^{1/4} v_0 \qquad \ldots \quad (8c)$$

$$\alpha_3 = \frac{R}{2}\left(\frac{3}{a}\right)^{1/4} \qquad \ldots \quad (8d)$$

$$\alpha_4 = 0.5 v_0 \qquad \ldots \quad (8e)$$

The value of ϵ, if 1 Kgm of the gas undergoes the reaction completely ($\alpha = 1$), is

$$1.05 \times 10^{10} \text{ Kc/Kgm.}$$

$\overline{C}_v$ can be taken to be the value of the specific heat for a perfect non-degenerate diatomic gas $= 3.5$ Kc/Kgm.

$$a = 1.81 \times 10^{-25} \text{ Kc/cc}/T^4$$

$$v_0 = 11.14 \times 10^6 \text{ cc/Kgm.}$$

Putting these values eqn. (8) becomes

$$8.07 \times 10^6 p_r^{1/4} + 3.5 p_r v - 5.57 \times 10^6 p_r - 1.13 \times 10^{13} p_r^{1/4}/v - 1.05 \times 10^{10}\alpha = 0$$

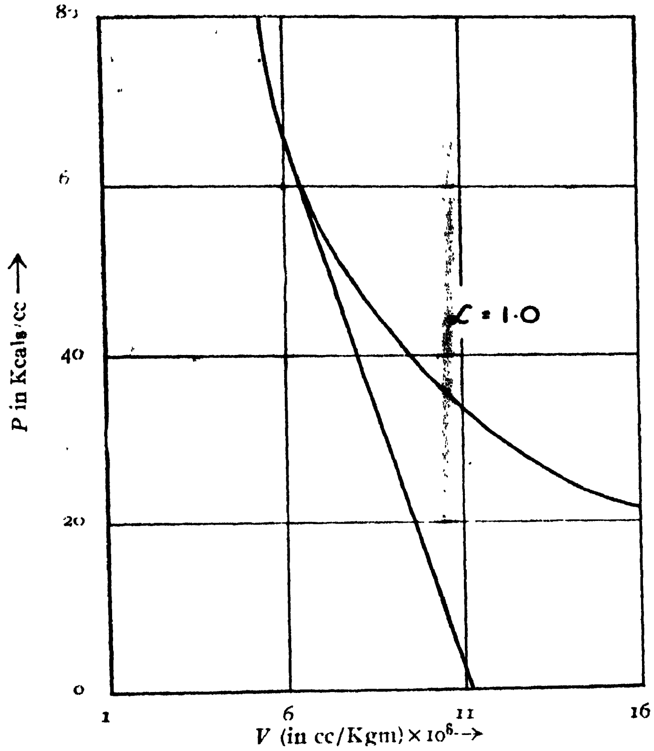

FIG. 1. R-H curves for proton gas

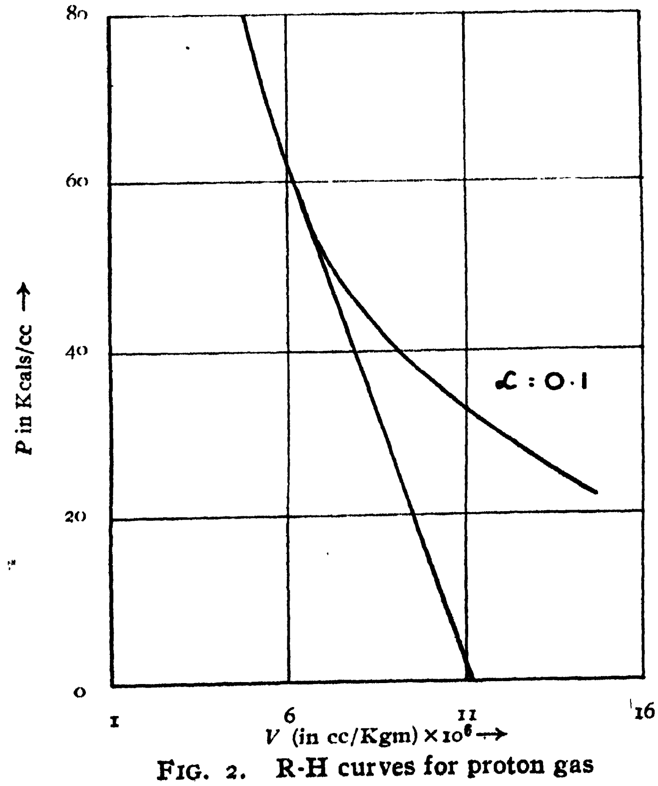

FIG. 2. R-H curves for proton gas

These curves have been drawn for $\alpha = 1.0$, 0.1 and 0.001 (see figures 1—3). The Chapman-Jouguet points, which are the points at which tangents from $(0\ v_0)$ touch the curves provide the data to calculate the following :

α	P dynes/cm	v cc/Kgm	T°K	D cm/sec	W cm/sec
1.0	2.51×10^{13}	6.58×10^{6}	1.0×10^{7}	8.26×10^{8}	3.39×10^{8}
0.1	2.04×10^{12}	5.80×10^{6}	5.84×10^{6}	2.64×10^{8}	1.25×10^{8}
0.001	3.09×10^{10}	4.71×10^{6}	1.62×10^{6}	2.51×10^{7}	1.19×10^{7}

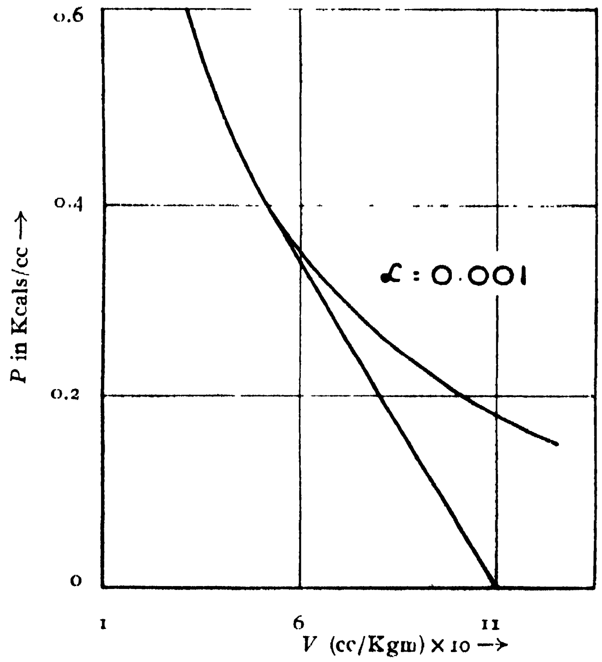

FIG. 3. R-H curves for proton gas

For the first two values of α, $p_r >> p$, but for $\alpha = 0.001$ both p_r and p are comparable. Figure 3 gives p_r ; then p is known from equation (7) whence by virtue of equations (1) and (2) various parameters are calculated. (*cf.*—Calculations made by Caldirola (1948) for uranium, who has taken account of p_r only, without introducing α).

ACKNOWLEDGMENT

The author is grateful to Dr. D. S. Kothari, Scientific Adviser to the Govt. of India, Ministry of Defence, for suggesting the problem and for his interest during the course of the work.

REFERENCE

Caldirola, 1948, *J. Chem. Phys.*, **16**, 846.